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SPECIFICATION

DIGITAL PHASE LOCKED LOOP CIRCUIT

5 TECHNICAL FIELD

The present invention relates to a digital phase locked loop circuit which is particularly suitable for generating sampling clock signals for sampling reproduced information obtained from the read heads of a magnetic tape apparatus.

10

BACKGROUND ART

When reproducing information recorded on a recording medium such as an optical disk, optical-magnetic disk, magnetic disk, or magnetic tape, it is necessary to generate sampling clock signals synchronized with the pulse train which is the reproduced information obtained from the read heads.

Phase locked loop circuits are widely used to generate this type of sampling clock signals. Phase locked loop circuits may be analog circuits or digital circuits. The digital circuits include partially digital circuits which partly include analog components such as oscillator portions, and completely digital circuits which do not include any analog components.

Of these phase locked loop circuits, the completely digital phase locked loop circuits have the advantages that they can be integrated to a very high degree and do not require various types of adjustments. An example of such a phase locked loop circuit is disclosed in U.S. Patent No. 5,442,315.

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However, various problems occur with this type of conventional digital phase locked loop circuit, especially when employed in the playback circuit of a magnetic tape apparatus.

In a magnetic tape apparatus, for example, a phenomenon
5 called "drop out" occurs wherein reproduced information is not attained. This is caused by defects in the magnetic tape medium itself, or the adhesion of dust or dirt to the magnetic heads. When drop out occurs, the phase locked loop circuit slips from a state where the input frequency and phase to be locked are normal
10 and drops out of lock. A conventional phase locked loop circuit does not have a function of detecting this dropping from lock for each channel. Moreover, after the loop drops out of lock because of drop out, even if normal reproduced information is input, the mobile frequency cannot be easily synchronized
15 because the mobile frequency slips with respect to input and the time to recover the locked state is long.

Also, in a magnetic tape apparatus, the magnetic tape travels while in contact with the magnetic heads and therefore the traveling speed of the magnetic tape varies because of
20 variations in the frictional resistance between the magnetic tape and magnetic head due to the capacity of the traveling motor, variations in the exciting current of the traveling motor, variations in tape tension, or the adhesion of dust and dirt. Such variations in the traveling speed are especially large in
25 comparison to the variations in rotation speed of different types of disks.

Variations in traveling speed occur in the same way during writing and reading, but may also occur in mutually opposite

directions. In this case, the result is that the traveling speed during writing and the traveling speed during reading vary to extremes and the phase locked loop circuit may not be able to track the variations.

5 Consequently, while performing reading at the same time as writing, it is necessary to monitor variations in traveling speed continually and when the traveling speed varies in excess of a prescribed range, to execute a process to rewind the magnetic tape once and perform writing once more. However, a conventional
10 digital phase locked loop circuit does not have a function for monitoring variations in the traveling speed of the recording medium.

DISCLOSURE OF THE INVENTION

15 It is, therefore, an object of the present invention to provide a digital phase locked loop circuit that can detect lock slippage promptly for each channel.

 Another object of the present invention is to provide a digital phase locked loop circuit that can monitor the playback
20 speed of reproduced information continually.

 According to a first aspect of the present invention, there is provided a digital phase locked loop circuit for generating sampling clock signals used with respect to a plurality of channels for sampling reproduced information simultaneously
25 from a plurality of tracks of a recording medium, comprising an average frequency computing circuit for calculating an average frequency of the phase locked sampling clock signals in selected channels and feeding back the calculated average to the phase

locked loop, wherein the average frequency computing circuit outputs a frequency error signal with respect to any channel in which the frequency of the sampling clock signals is outside an allowable frequency range.

5 Preferably, the average frequency computing circuit comprises a comparator for comparing the frequency of the sampling clock signals in each channel with the allowable frequency range and for outputting a frequency error signal for any channel in which the frequency of the sampling clock signals
10 is outside an allowable frequency range.

 Preferably, the average frequency computing circuit calculates the average frequency of the sampling clock signals in the selected channels which do not include those channels in which the frequency of the sampling clock signals is outside the
15 allowable frequency range.

 Preferably, the digital phase locked loop circuit further comprises a register for adjustably setting a value representative of an allowable deviation. In this case, the allowable frequency range is determined on the basis of the
20 average frequency calculated by the average frequency computing circuit and the set value from the register.

 Preferably, the digital phase locked loop circuit further comprises a gate circuit for masking the frequency error signal in an operational mode other than a tracking mode.

25 Preferably, the average frequency computing circuit divides the plurality of channels into a plurality of groups each of which includes at least two channels. In this case, the frequencies of the sampling clock signals for the plurality of

channels are summed repetitively and cumulatively group by group for calculating the average frequency.

Preferably, the average frequency computing circuit is reset in a calibration mode for performing calibration of the
5 frequencies to be phase locked.

Preferably, the average frequency computing circuit includes a holding circuit for holding the average frequency which has been obtained immediately previously when all of the channels are in an operational mode other than a tracking mode.

10 Preferably, when the average frequency computing circuit outputs a frequency error signal for any channel, resynchronization of the sampling clock signals is performed only for the erring channel.

Preferably, the resynchronization of the sampling clock
15 signals is performed at high speed in a lead-in mode by using the average frequency calculated by the average frequency computing circuit.

According to a second aspect of the present invention, there is provided a digital phase locked loop circuit for generating
20 sampling clock signals used with respect to a plurality of channels for sampling reproduced information simultaneously from a plurality of tracks of a recording medium, comprising an average frequency computing circuit for calculating an average frequency of the phase locked sampling clock signals in selected
25 channels and feeding back the calculated average to the phase locked loop, wherein the average frequency computing circuit comprises a speed variation detecting circuit for determining

a rate of variation of the average frequency in a predetermined time.

Preferably, the rate variation detecting circuit includes a comparator for comparing a variation width, in the
5 predetermined time, of the average frequency determined by the average frequency computing circuit with an allowable variation range and for outputting a speed error signal if the variation width is outside the allowable variation range.

Preferably, the speed variation detecting circuit is
10 capable of adjustably setting the predetermined time.

The various features and advantages of the present invention will be apparent on the basis of the embodiments given below with reference the attached drawings.

15 BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a circuit block diagram of a digital phase locked loop circuit according to an embodiment of the present invention.

Figure 2 is a circuit block diagram of a GAC circuit incorporated in the digital phase locked loop circuit shown in
20 Figure 1.

Figure 3 is a timing chart for illustrating the resynchronization operation performed by the digital phase locked loop circuit shown in Figure 1.

Figure 4 is a circuit block diagram of the tape speed
25 variation detecting circuit provided for the GAC circuit shown in Figure 2.

Figure 5A through Figure 5D are timing charts for illustrating the sampling operation of the tape speed variation detecting circuit shown in Figure 4.

5 BEST MODE FOR CARRYING OUT THE INVENTION

An embodiment of the present invention is explained below on the basis of Figures 1 through 5.

As shown in Figure 1, the digital phase locked loop circuit according to the embodiment of the present invention includes
10 eight DTG (digital time generation) circuits 1₁~1₈, eight BSADPLL (bit stream asynchronous digital phase locked loop) circuits 2₁ through 2₈, eight DRU (data recovery unit) circuits 3₁~3₈, one GAC (global average clock) circuit 4, one interface circuit 5, one register file 6, and one frequency halving circuit 7.

15 This digital phase locked loop circuit is a phase locked loop circuit that is completely digital and is used to generate sampling clock signals for sampling reproduced information obtained from the read heads of a magnetic tape apparatus. The magnetic tape has 128 tracks, and the magnetic heads are designed
20 to read 16 tracks simultaneously. Specifically, 16 groups of magnetic heads are provided, and each group comprises a total of four magnetic heads which include a write head and a read head for reading and writing one track in the forward direction as well as a write head and a read head for reading and writing one
25 track in the reverse direction.

The circuit shown in Figure 1 is incorporated in one IC (integrated circuit) chip and is designed to process 16 channels

of reproduced information with two IC chips. 16 channels of reproduced information may be processed with only one IC chip.

The DTG circuits $1_1 \sim 1_8$ output relative position signals and PKPLS detection signals to the BSADPLL circuits $2_1 \sim 2_8$ with the
5 input of these signals PKPLS1~PKPLS8. The signals PKPLS1~PKPLS8 are signals that become high level when the playback pulse obtained from the read head is "1". Each of the relative position signals is a signal including six bits of binary data indicating the respective position of the signals PKPLS1 through PKPLS8
10 relative to the standard clock signal 1XCLOCK.

With the input of the relative position signals and PKPLS detection signals from the DTG circuits $1_1 \sim 1_8$ and the signal GAC corresponding to the average frequency value from the GAC circuit 4, the BSADPLL circuits $2_1 \sim 2_8$ output an input phase estimation
15 signal corresponding to the phase of the signals PKPLS1~PKPLS8 and a DPLL phase integrator output phase signal to the DRU circuits $3_1 \sim 3_8$, while outputting signals PLLfreq1~PLLfreq8 to the GAC circuit 4. The signals PLLfreq1~PLLfreq8 correspond to the frequencies of the signals PKPLS1~PKPLS8 and are 15 bits of data
20 including a sign bit. The signals PLLfreq1~PLLfreq8 are established so that their values become 0 when the frequency in the phase locked state corresponding to the frequencies of the signals PKPLS1~PKPLS8 are equal to the standard clock signal 1XCLOCK.

25 With the input of the input phase estimation signals and the PLL phase integrator output phase signals from the BSADPLL circuits $2_1 \sim 2_8$, the DRU circuits $3_1 \sim 3_8$ output the signals PDATA

1~PDATA 8 corresponding to the reproduced information and the sampling clock signals PCLK1~PCLK8 thereof.

With the input of the signals PLLfreq1~PLLfreq 8 from the BSADPLL circuits 2₁~2₈, the GAC circuit 4 detects the average
5 frequency of the signals PKPLS1~PKPLS8 for eight channels and outputs the signal GAC. The GAC circuit 4 also outputs the speed error signals SPCHNG when the variation band of the signal GAC exceeds the allowable range within the prescribed time period.

The interface circuit 5 controls communication between the
10 digital phase locked loop circuit and the external circuits.

The register file 6 includes a plurality of registers for holding various types of set values supplied from a CPU (central processing unit), not shown.

The frequency halving circuit 7 divides the clock signal
15 2XCLOCK in half and generates the standard clock signal 1XCLOCK.

As shown in Figure 2, the GAC circuit 4 includes eight comparators 11₁~11₈, six adders 12₁~12₆, eight registers 13₁~13₈, a circuit 14 for determining the number of input channels (hereafter referred to as "input-channels-number determining
20 circuit"), a GAC generating circuit 15, a frequency error value setting circuit 16, a gate circuit 17, eight AND circuits 18₁~18₈, and an OR circuit 19. Note that the tape speed variation detecting circuit is not shown in Figure 2.

The input-channels-number determining circuit 14 includes
25 an adder 21, seven AND circuits 22₁~22₇, two OR circuits 23₁ and 23₂, and an inverter 24.

The GAC generating circuit 15 includes a register 26.

The comparators $11_1 \sim 11_8$ compare, for each channel, the signals PLLfreq1~PLLfreq8 from the BSADPLL circuits $2_1 \sim 2_8$ with the maximum allowable frequency value and the minimum allowable frequency value from the frequency error value setting circuit

5 16. If the signals PLLfreq1~PLLfreq8 are not within the allowable frequency range, the comparators output a high level signal to the gate circuit 17 and the AND circuits $18_1 \sim 18_4$. The comparators $11_1, 11_2$ output the signals PLLfreq1 and PLLfreq2 to the adder 12_1 . The comparators $11_3, 11_4$ output the signals PLLfreq3 and

10 PLLfreq4 to the adder 12_2 . The comparators $11_5, 11_6$ output the signals PLLfreq5 and PLLfreq6 to the adder 12_3 . The comparators $11_7, 11_8$ output the signals PLLfreq7 and PLLfreq8 to the adder 12_4 .

The adder 12_1 adds the signals PLLfreq1 and PLLfreq2 from

15 the comparators $11_1, 11_2$ and outputs the sum to the AND circuit 18_5 . The adder 12_2 adds the signals PLLfreq3 and PLLfreq4 from the comparators $11_3, 11_4$ and outputs the sum to the AND circuit 18_6 . The adder 12_3 adds the signals PLLfreq5 and PLLfreq6 from the comparators $11_5, 11_6$ and outputs the sum results to the AND

20 circuit 18_7 . The adder 12_4 adds the signals PLLfreq7 and PLLfreq8 from the comparators $11_7, 11_8$ and outputs the sum to the AND circuit 18_8 .

The adder 12_5 adds data contained the register 13_2 and data contained in the register 13_4 and outputs the sum to the AND

25 circuit 22_6 of the input-channels-number determining circuit 14. The adder 12_6 adds data contained the register 13_6 and data contained in the register 13_8 , and outputs the sum to the AND circuit 22_7 of the input-channels-number determining circuit 14.

Each of the registers 13_1 , 13_3 , 13_5 , and 13_7 is a one-bit register for storing the output of the AND circuits $18_1 \sim 18_4$, respectively.

Each of the registers 13_2 , 13_4 , 13_6 , and 13_8 is a 16-bit register for storing the output of the AND circuits $18_5 \sim 18_8$, respectively.

The input-channels-number determining circuit 14 supplies the GAC generating circuit 15 with information for computing the average frequency signal GAC.

10 The GAC generating circuit 15 computes the signal GAC on the basis of the information from the input-channels-number determining circuit 14 and outputs the result to the frequency error value setting circuit 16 and the BSADPLL circuits $2_1 \sim 2_8$. The GAC generating circuit 15 becomes effective when the signal
15 GACEN from the register file 6 is at high level, and outputs all zeros when the signal GACEN is low level.

On the basis of the signal GAC from the GAC generating circuit 15 and the 13-bit setting data from the register file 6, the frequency error value setting circuit 16 calculates the
20 maximum allowable frequency value and the minimum allowable frequency value and outputs them to the comparators $11_1 \sim 11_8$.

When the signal GACEN from the register file 6 is at high level, the gate circuit 17 outputs a frequency error signal PLLERR1~8 from the comparators $11_1 \sim 11_8$ of the corresponding
25 channel if one or more of the signals PHOK1~PHOK8 generated on the basis of the signal TMSNS is at high level. The signal TMSNS and the signals PHOK1 through PHOK8 are discussed in detail below.

The AND gate 18₁ outputs a high level signal to the AND gate 18₅ and the register 13₁ when the frequency error signal from the comparator 11₁ and the frequency error signal from the comparator 11₂ are both at high level.

5 The AND gate 18₂ outputs a high level signal to the AND gate 18₆ and the register 13₃ when the frequency error signal from the comparator 11₃ and the frequency error signal from the comparator 11₄ are both at high level.

10 The AND gate 18₃ outputs a high level signal to the AND gate 18₇ and the register 13₅ when the frequency error signal from the comparator 11₅ and the frequency error signal from the comparator 11₆ are both at high level.

15 The AND gate 18₄ outputs a high level signal to the AND gate 18₈ and the register 13₇ when the frequency error signal from the comparator 11₇ and the frequency error signal from the comparator 11₈ are both at high level.

The AND gate 18₅ includes 16 AND elements and outputs the 16-bit sum from the adder 12₁ to the register 13₂ when a high level signal is input from the AND circuit 18₁.

20 The AND gate 18₆ includes 16 AND elements and outputs the 16-bit sum from the adder 12₂ to the register 13₄ when a high level signal is input from the AND circuit 18₂.

25 The AND gate 18₇ includes 16 AND elements and outputs the 16-bit summation from the adder 12₃ to the register 13₆ when a high level signal is input from the AND circuit 18₃.

The AND gate 18₈ includes 16 AND elements and outputs the 16-bit summation from the adder 12₄ to the register 13₈ when a high level signal is input from the AND circuit 18₄.

The OR circuit 19 outputs a high level signal to the register 26 of the GAC generating circuit 15 when one or more of the signals PHOK1~PHOK8 is at high level.

5 The adder 21 generates signals CONT1 and CONT2 for output to the AND circuit 22, and the GAC generating circuit 15 by summing the one-bit data stored in the registers 13₁, 13₃, 13₅, and 13₇, respectively.

10 The AND circuit 22₁ outputs a high level signal to the AND circuit 22₄ when the contents of the registers 13₁ and the contents of the register 13₃ are both at high level.

The AND circuit 22₂ outputs a high level signal to the AND circuit 22₅ when the contents of the registers 13₃ and the contents of the register 13₅ are both at high level.

15 The AND circuit 22₃ outputs a high level signal to the AND circuits 22₄ and 22₅ and the inverter 24 when both signals CONT1 and CONT2 from the adder 21 are at high level.

The AND circuit 22₄ outputs high level signal to the OR circuit 23₁ when the signals from the AND circuits 22₁ and 22₃ are both at high level.

20 The AND circuit 22₅ outputs a high level signal to the OR circuit 23₂ when the signals from the AND circuits 22₂ and 22₃ are both at high level.

25 The AND circuit 22₆ includes 17 AND elements and outputs the 17-bit sum from the adder 12₅ to the GAC generating circuit 15 when the signal from the OR circuit 23₁ is at high level.

The AND circuit 22₇ includes 17 AND elements and outputs the 17-bit sum from the adder 12₆ to the GAC generating circuit 15 when the signal from the OR circuit 23₂ is high level.

The OR circuit 23₁ outputs a high level signal to the AND circuit 22₆ when at least one of the signals from the AND circuit 22₄ and the inverter 24 is at high level.

The OR circuit 23₂ outputs a high level signal to the AND circuit 22₇ when at least one of the signals from the AND circuit 22₅ and the inverter 24 is at high level.

The inverter 24 inverts the signal from the AND circuit 22₃ for output to the OR circuits 23₁ and 23₂.

The register 26 operates when the signal from the OR circuit 19 is at high level while maintaining its contents without alteration when the signal from the OR circuit 19 is at low level. Further, the register 26 is reset when the signal CALIBRATE for calibrating the frequency to be phase-locked becomes high level.

Each circuit in Figure 2 operates in synchronization with the standard clock signal 1XCLOCK. The signals PLLfreq1~PLLfreq8 input to the comparators 11₁~11₈ of each channel are compared with the maximum allowable frequency value and minimum allowable frequency value from the frequency error value setting circuit 16.

Assuming that the value of the GAC signal is A and that the set value supplied to the frequency error value setting circuit 16 from the register file 6 is B, the maximum allowable frequency value is $A + B$, whereas the minimum allowable frequency value is $A - B$.

When the signals PLLfreq1~PLLfreq8 are within the allowable frequency range between the maximum allowable frequency value and the minimum allowable frequency value, a high level signal

is output respectively from the comparators 11₁~11₈ to the AND circuits 18₁~18₄.

Specifically, a high level signal is output from the comparators 11₁ and 11₂ to the AND circuit 18₁. A high level signal is output from the comparators 11₃ and 11₄ to the AND circuit 18₂. A high level signal is output from the comparators 11₅ and 11₆ to the AND circuit 18₃. A high level signal is output from the comparators 11₇ and 11₈ to the AND circuit 18₄.

Consequently, in the case where both the signals PLLfreq1 and PLLfreq2 are within the allowable frequency range, a high level signal is output from the AND circuit 18₁ to the AND circuit 18₅ and the register 13₁. In the case where both the signals PLLfreq3 and PLLfreq4 are within the allowable frequency range, a high level signal is output from the AND circuit 18₂ to the AND circuit 18₆ and the register 13₃. In the case where both the signals PLLfreq5 and PLLfreq6 are within the allowable frequency range, a high level signal is output from the AND circuit 18₃ to the AND circuit 18₇ and the register 13₅. In the case where both the signals PLLfreq7 and PLLfreq8 are within the allowable frequency range, a high level signal is output from the AND circuit 18₄ to the AND circuit 18₈ and the register 13₇.

On the other hand, the signals PLLfreq1~PLLfreq8 input to the comparators 11₁~11₈ of each channel are also output to the adders 12₁~12₄.

Specifically, the signals PLLfreq1 and PLLfreq2 input to the comparators 11₁ and 11₂ are output to the adder 12₁, summed by the adder 12₁, and output to the AND circuit 18₅. The signals PLLfreq3 and PLLfreq4 input to the comparators 11₃ and 11₄ are

output to the adder 12₂, summed by the adder 12₂, and output to the AND circuit 18₆. The signals PLLfreq5 and PLLfreq6 input to the comparators 11₅ and 11₆ are output to the adder 12₃, summed by the adder 12₃, and output to the AND circuit 18₇. The signals
5 PLLfreq7 and PLLfreq8 input to the comparators 11₇ and 11₈ are output to the adder 12₄, summed by the adder 12₄, and output to the AND circuit 18₈.

Consequently, if both the signals PLLfreq1 and PLLfreq2 are within the allowable frequency range, the sum of those is stored
10 in the register 13₂. If both the signals PLLfreq3 and PLLfreq4 are within the allowable frequency range, the sum of those is stored in the register 13₄. If both the signals PLLfreq5 and PLLfreq6 are within the allowable frequency range, the sum of those is stored in the register 13₆. If both the signals PLLfreq7
15 and PLLfreq8 are within the allowable frequency range, the sum of those is stored in the register 13₈.

The contents of the registers 13₁, 13₃, 13₅, and 13₇ are summed by the adder 21 in the input-channels-number determining circuit 14. That sum is supplied as the control signals CONT1 and CONT2
20 to the GAC generating circuit 15 and the AND circuit 22₃.

There are a total of four groups of signals PLLfreq each group of which includes two signals, that is; the signals PLLfreq1 and PLLfreq2, the signals PLLfreq3 and PLLfreq4, the signals PLLfreq5 and PLLfreq6, and the signals PLLfreq7 and PLLfreq8.
25 In the case where there are three groups wherein both signals PLLfreq are within the allowable frequency range, a high level signal is output from the AND circuit 22₃.

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Consequently, when there are zero, one, two, or four groups with both signals PLLfreq lying within the allowable frequency range, a high level signal is output from the inverter 24 to the OR circuits 23₁ and 23₂, from which a high level signal is output to the AND circuits 22₆ and 22₇. Therefore, the sums of the adders 12₅ and 12₆ are output from the AND circuits 22₆ and 22₇ to the GAC generating circuit 15.

On the other hand, different results are obtained in the case where there are three groups wherein both signals PLLfreq are within the allowable frequency range. Specifically, when all of the signals PLLfreq1 through PLLfreq4 are within the allowable range, a high level signal is output from the AND circuit 22₁ to the AND circuit 22₄, which in turn outputs a high level signal to the OR circuit 23₁, whereas the sum from the adder 12₅ is output through the AND circuit 22₆ to the GAC generating circuit 15. Further, when all of the signals PLLfreq5 through PLLfreq8 are within the allowable range, a high level signal is output from the AND circuit 22₂ to the AND circuit 22₅, which in turn outputs a high level signal to the OR circuit 23₂, whereas the sum from the adder 12₆ is output through the AND circuit 22₇ to the GAC generating circuit 15. In other words, in the case where there are three groups wherein both signals PLLfreq are within the allowable frequency range, only the value of the sum of two groups of four signals PLLfreq (i.e., the signals PLLfreq1~PLLfreq4 and the signals PLLfreq5 ~PLLfreq8) not including signals PLLfreq outside the allowable frequency range is supplied to the GAC generating circuit 15.

The GAC generating circuit 15 adds the sum from the AND circuits 22, and 22, and generates the signal GAC by dividing the sum according to the value of the signals CONT1 and CONT2 from the adder 21 for storing in the register 26.

5 In other words, as shown in Table 1 below, when there are four groups wherein both signals PLLfreq lie within the allowable frequency range, all signals PLLfreq1~PLLfreq8 are summed, and the resulting sum is divided by eight to provide the signal GAC. When there are three groups wherein both signals PLLfreq lie
10 within the allowable frequency range, four signals PLLfreq are summed, and the resulting sum is divided by four to provide the signal GAC. When there are two groups wherein both signals PLLfreq lie within the allowable frequency range, four signals PLLfreq are summed, and the resulting sum is divided by four to provide
15 the signal GAC. When there is one group wherein both signals PLLfreq lie within the allowable frequency range, two signals PLLfreq are summed, and the resulting sum is divided by two to provide the signal GAC. When there are no groups wherein both signals PLLfreq lie within the allowable frequency range, the
20 resulting sum is zero, so that the quotient will be the same regardless of the divisor. In this case, however, since each of the signals CONT1 and CONT2 is the same as in the case where there are four groups with both signals laying within the allowable frequency range, the sum will be divided by eight to
25 provide the signal GAC.

TABLE 1

| Number of Groups without Error | 4 | 3 | 2 | 1 | 0 |
|--------------------------------|---|---|---|---|---|
| CONT1 | 0 | 1 | 1 | 0 | 0 |
| CONT2 | 0 | 1 | 0 | 1 | 0 |
| Divisor | 8 | 4 | 4 | 2 | 8 |

Such a process for dividing the signals PLLfreq1~PLLfreq8
 5 into four groups of two is advantageous for simplifying the
 circuit arrangement.

As a result of this simplification of the circuit
 arrangement, the signal GAC becomes zero in the case where one
 of the signals PLLfreq in every group is outside the allowable
 10 frequency range, for example. The signal GAC of 0 means that the
 average frequency is equal to the frequency of the standard clock
 signals 1XCLOCK. The values of the setting data supplied from
 the register file 6 to the frequency error value setting circuit
 16 are determined appropriately so that the remaining normal
 15 signals PLLfreq do not fall outside the allowable frequency range
 in this case as well.

The signal GAC obtained in this way is fed back to the
 frequency error value setting circuit 16 and the BSADPLL circuits
 2₁~2₈, while also being supplied to the tape speed variation
 20 detecting circuit contained in the GAC circuit 4.

In the case where the signals PLLfreq1~PLLfreq8 are outside
 the allowable frequency range, low level frequency error signals
 PLLERR1~PLLERR8 are output from the comparators 11₁~11₈ via the
 gate circuit 17.

As shown in Figure 3, when the reading position of each read head reaches the burst zone of the magnetic tape 31, the signal TMSNS of each channel supplied from outside the digital phase locked loop circuit becomes high. On the basis of this signal TMSNS, the signals SGLOBAL and PHOK for each channel are generated within that digital phase locked loop circuit. The signal SGLOBAL rises after a 2-bit cell from the rise of the signal TMSNS. The signal PHOK rises after a 40-bit cell from the rise of the signal TMSNS.

When the signal TMSNS rises, the signal GAC held in the register 26 of the GAC generating circuit 15 is taken out by the BSADPLL circuits $2_1 \sim 2_8$, which then oscillate at the frequency determined by the signal GAC. During the period of the 40-bit cell before the signal PHOK rises, the BSADPLL circuits $2_1 \sim 2_8$ perform synchronition of the signal PKPLS in the lead-in mode. When the signal PHOK rises, the BSADPLL circuits $2_1 \sim 2_8$ switch to the tracking mode and perform synchronous tracking.

When the frequency of the signal PKPLS of any channel becomes abnormal due for example to drop out after synchronization is complete, the frequency error signal PLLERR of that channel becomes low. The frequency error signal PLLERR is inverted and latched within the digital phase locked loop circuit and output therefrom as the frequency error signal DEADPLL. Accordingly, when the reading position of the read head reaches the resynchronization burst zone of the magnetic tape 31, the signal TMSNS supplied from outside the digital phase locked loop circuit is reset and becomes low, and rises after an 8-bit cell.

Consequently, the same operation is repeated for a relevant channel as performed when the read position of the read head matches the burst zone of the magnetic tape 31, so that the BSADPLL circuits synchronize the signal PKPLS in the lead-in mode. In
5 the lead-in mode, the normal state is promptly recovered because the tracking gain is higher than in the tracking mode. The frequency error signal DEADPLL is reset when the signal TMSNS is reset.

In this way, a shift from the synchronization state can be
10 detected immediately for each channel because the frequency error signals PLLERR1~8 are output from the comparators 11₁~11₈ for each channel.

Further, it is possible to accurately determine the average frequency because erring channels are excluded from the
15 calculation of the signal GAC.

Further, the digital phase locked loop circuit can respond flexibly to various changes of specifications because the allowable frequency range can be altered freely by changing the set values in the registers of the register file 6 supplied to
20 the frequency error value setting circuit 16.

The frequency error signals PLLERR1~8 are not output except during the tracking mode, because the signals PHOK1~8 are supplied to the gate circuit 17 for gating the frequency error signals PLLERR1~8.

25 Because the signal based on the signals PHOK1~8 is supplied from the OR circuit 19 to the register 26 of the GAC generating circuit 15, synchronization can be performed promptly using the

signal GAC held in the register 26 when the read position of the read head matches the burst zone of the magnetic tape 31.

As shown in Figure 4, the tape speed variation detecting circuit 40 incorporated in the GAC circuit 4 includes a counter 41, adders 42 and 43, registers 44 through 47, dividers 48 and 49, a subtracter 50, a register 51, a comparator 52, a register 53, an inverter 54, an OR circuit 55, and an inverter 56.

The counter 41 divides the input clock signals by 128. Specifically, for each count of 64 input clock signals, the signal output to the registers 44 and 47 and the inverter 54 is inverted alternately between high level and low level. Further, the counter 41 divides the input clock signals by 64. Specifically, the signal output to the register 51 is inverted alternately between high level and low level for each count of 32 input clock signals.

The adder 42 adds the signal GAC from the register 26 in the GAC generating circuit 15 to the output from the register 44, and supplies the sum to the register 44.

The adder 43 adds the signal GAC from the register 26 in the GAC generating circuit 15 to the output from the register 45, and supplies the sum to the register 45.

The register 44 operates in synchronization with clock signals input to the counter 41. The register 44 takes out the stored sum from the adder 42 for output to the register 46 and adder 42 when the signal supplied from the counter 41 to the reset terminal is low.

The register 45 operates in synchronization with clock signals input to the counter 41. The register 45 takes out the stored sum from the adder 43 for output to the register 47 and

adder 43 when the signal supplied from the inverter 54 to the reset terminal is low.

The register 46 operates in synchronization with clock signals input to the counter 41. When the signal supplied from the inverter 54 to the enable terminal is high, the register 46 takes out the stored sum from the register 44 for output to the divider 48.

The register 47 operates in synchronization with clock signals input to the counter 41. When the signal supplied from the counter 41 to the enable terminal is high, the register 47 takes out the stored sum from the register 45 for output to the divider 49.

The divider 48 divides the stored sum from the register 46 by 64 for output of the quotient to the subtracter 50.

The divider 49 divides the stored sum from the register 47 by 64 for output of the quotient to the subtracter 50.

The subtracter 50 calculates the difference between the output from the divider 48 and the output from the divider 49 for feeding the resulting difference to the register 51.

The register 51 synchronizes in operation with the signals input from the counter 41 to the clock signal input terminal. It takes out the calculated difference from the subtracter 50 for output to the comparator 52.

The comparator 52 compares the difference from the register 51 with the set value from the register file 6 for output of a high level signal to the register 53 if the difference from the register 51 is within the allowable range according to the set value from the register file 6.

The register 53 synchronizes in operation with the standard clock signals 1XCLOCK. It takes out the signal from the comparator 52 for output of that signal as the speed error signal SPCHNG.

5 The inverter 54 inverts the signal from the counter 41 for output to the registers 45 and 46.

The OR circuit 55 outputs a low level signal to the inverter 56 when all of the signals PHOK1~PHOK8 are low.

10 The inverter 56 inverts the signal from the OR circuit 55 for output of that signal as the reset signal to each circuit in the tape speed variation detecting circuit 40.

15 When all of the signals PHOK1~PHOK8 are low, the output of the OR circuit 55 turns to low level while the output of the inverter 56 turns to high level for output of a reset signal which is used to reset each circuit of the tape speed variation detecting circuit 40. In other words, the tape speed variation detecting circuit 40 operates only when one or more channels is in the tracking mode, as is clear from Figure 3.

20 One of the following signals is input to the counter 41: standard clock signals 1XCLOCK, clock signals 1/2XCLOCK obtained by dividing the standard clock signals 1XCLOCK by two, clock signals 1/4XCLOCK obtained by dividing the standard clock signals 1XCLOCK by four, clock signal 1/8XCLOCK obtained by dividing the standard clock signals 1XCLOCK by 8. The set value in a selected register of the register file 6 determines which
25 clock signals are input.

Assuming now that the standard clock signals 1XCLOCK are input to the counter 41, the output of the counter 41 becomes

low for a duration of 64 cycles of the standard clock signals 1XCLOCK. This causes the register 44 to be in an unreset state, the register 45 to be in a reset state, the register 46 to be in an enabled state, and the register 47 to be in a disabled state.

5 As a result, the signals GAC are cumulatively input to the adder 42 for summing every cycle of the standard clock signals 1XCLOCK and for storing the resulting sum in the register 46. The sum stored in the register 46 is divided by 64 in the divider 48, and the resulting quotient is output to the subtracter 50.

10 Upon lapse of a period of 64 cycles of the standard clock signals 1XCLOCK, the output of the counter 41 is inverted for causing the register 44 to be in a reset state, the register 45 to be in an unreset state, the register 46 to be in a disabled state, and the register 47 to be in an enabled state. This state
15 continues for 64 cycles of the standard clock signals 1XCLOCK. As a result, the average frequency signal GAC is cumulatively input to the adder 43 for summing every cycle of the standard clock signals 1XCLOCK and for storing the resulting sum in the register 47. The sum stored in the register 47 is divided by 64
20 in the divider 49 and the result is output to the subtracter 50. The output of the subtracter 50 is stored in the register 51 every 64 cycles of the standard clock signals 1XCLOCK.

Consequently, the register 51 stores the difference between the average of 64 GAC signals in a period of 64 cycles of the
25 standard clock signals 1XCLOCK and the average of 64 GAC signals in the next period of 64 cycles of the standard clock signals 1XCLOCK. The comparator 52 compares this difference with the standard value from a prescribed register of the register file

6. If the difference exceeds the standard value, a high level signal is output from the comparator 52. This high level signal is stored in the register 53 and is output as a speed error signal SPCHNG.

5 The same operations are repeated at every 64 cycles of the standard clock signals 1XCLOCK.

As discussed above, in the case where the standard clock signals 1XCLOCK are input to the counter 41, a GAC signal is taken out every cycle of the standard clock signals 1XCLOCK as shown
10 in Figure 5A, and the difference between the average of 64 GAC signals and the average of the subsequent 64 GAC signals is compared with a standard value. Thus, variations of the average frequency signal GAC are monitored every 64 cycles of the standard clock signals 1XCLOCK.

15 In the case where the clock signals $1/2XCLOCK$ obtained by dividing the standard clock signals 1XCLOCK by two are input to the counter 41, a GAC signal is taken out every two cycles of the standard clock signals 1XCLOCK as shown in Figure 5B, and the difference between the average of 64 GAC signals and the
20 average of the subsequent 64 GAC signals is compared with a standard value. Thus, variations of the average frequency signal GAC are monitored every 128 cycles of the standard clock signals 1XCLOCK.

25 In the case where the clock signals $1/4XCLOCK$ obtained by dividing the standard clock signals 1XCLOCK by four are input to the counter 41, a GAC signal is taken out every four cycles of the standard clock signal 1XCLOCK as shown in Figure 5C, and the difference between the average of 64 GAC signals and the

average of the subsequent 64 GAC signals is compared with a standard value. Thus, variations of the average frequency signal GAC are monitored every 256 cycles of the standard clock signal 1XCLOCK.

In the case where the clock signals $1/8 \times \text{XCLOCK}$ obtained by dividing the standard clock signals $1 \times \text{XCLOCK}$ by eight are input to the counter 41, a GAC signal is taken out every eight cycles of the standard clock signals $1 \times \text{XCLOCK}$ as shown in Figure 5D and the difference between the average of 64 GAC signals and the average of the subsequent 64 GAC signals is compared with a standard value. Thus, variations of the average frequency signal GAC are monitored every 512 cycles of the standard clock signal $1 \times \text{XCLOCK}$.

In this way, the time interval for monitoring variations of the average frequency signal GAC can be changed freely by switching the frequency of the clock signals XCLOCK supplied to the counter 41.

The speed error signal SPCHNG supplied from the register 53 of the tape speed variation detecting circuit 40 is output outside of the digital phase locked loop circuit. Variations of the average frequency signal GAC correspond to variations in the traveling speed of the magnetic tape 31. When the variations of the average frequency signal GAC is outside the allowable range, this indicates that the variations in the traveling speed of the magnetic tape 31 exceed the allowable range.

When the speed error signal SPCHNG turns to high level by a so-called read-back check, a so-called retry operation is performed wherein writing onto the magnetic tape 31 is

temporarily suspended and the magnetic tape 31 is rewound for
rewriting the same data. In the read-back check, the standard
value supplied to the comparator 52 in the tape speed variation
detecting circuit 40 is a very strict value compared to that
5 supplied for normal reading. This is because, during normal
reading, the traveling speed of the magnetic tape 31 may vary
oppositely to writing, so that strict control over the allowable
value of the variation in the traveling speed of the magnetic
tape 31 during writing ensures reliable reading during normal
10 reading.